Li-ion Pouch Cell Designs; Are They Ready for Space Applications?

by
Eric Darcy
NASA-JSC

For the
Large Li-ion Battery Technology and Application Symposium
of the
Advanced Automotive Battery Conference
8 Feb 2012
Orlando, FL
Li-ion Pouch Cells

Outline

- Various Space Applications
- Pouch cell design evaluation
- Cell lot uniformity, why that’s important
  - Soft Short Screening
- Performance at 4C Discharge Rates
- Pouch Corrosion
- Forward plans
  - Cycle life durability
  - Seals
  - Manufacturing quality
- Conclusions
Current EVA Batteries

- **Pistol Grip Tool (PGT) Battery**
  - Nickel Metal Hydride (NiMH)

- **Helmet Light (EHIP) Battery**
  - Nickel Metal Hydride (NiMH)

- **Rechargeable EVA Battery Assembly (REBA)**
  - Nickel Metal Hydride (NiMH)

- **Long Life Battery (LLB) for EMU**
  - Lithium ion (Li-ion)

- **Simplified Aid For EVA Rescue (SAFER) Battery**
  - Lithium Manganese Dioxide (Li-MnO$_2$)
Critical Manned Spacecraft Batteries

- **Spacesuit (Li-ion first flight in 2011)**
  - 20V, 35Ah, 50 cycle, 5 yr life
  - Power all life support systems of the spacesuit

- **Robonaut (proposed)**
  - 96V, 26Ah, few cycles, 5 yr life
  - Eventually operates side-by-side with spacewalkers

- **Orion Crew Exploration Vehicle (201?)**
  - 120V, 30Ah, 3000 cycles, 3 yr life
  - 6-man capsule

- **International Space Station (Li-ion planned for 2017)**
  - 120V, 120 Ah, 38,000 cycles, 6.5 yr life
  - Main power source during LEO eclipses

- **VASIMR (proposed)**
  - 425V, 50 kWh discharged in 15 minutes
  - Main power for RF generator firings

- **Safety Requirements**
  - Two-fault tolerant to most catastrophic hazards
  - Electrolyte leakage and cell internal shorts hazards controlled by a defined process that applies all reasonable mitigating measures
Assessment of Cell Designs

<table>
<thead>
<tr>
<th>#</th>
<th>Vendor</th>
<th>P/N</th>
<th>Mass (g)</th>
<th>Rated Discharge Capacity (Ah)</th>
<th>Standard Charge Regime</th>
<th>Max Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A123</td>
<td>PHEV</td>
<td>480</td>
<td>20</td>
<td>3.6V at C/2 with C/50 taper current limit</td>
<td>80A to 2.0V</td>
</tr>
<tr>
<td>2</td>
<td>Dow Kokam</td>
<td>SLPB75106100</td>
<td>165</td>
<td>8</td>
<td>4.2V at C/2 with C/50 taper current limit</td>
<td>32A to 2.7V</td>
</tr>
<tr>
<td>3</td>
<td>EIG</td>
<td>C020</td>
<td>425</td>
<td>20</td>
<td>4.15V at C/2 with C/50 taper current limit</td>
<td>80A to 2.5V</td>
</tr>
<tr>
<td>4</td>
<td>LG Chem</td>
<td>P1</td>
<td>383</td>
<td>15</td>
<td>4.15V at C/2 with C/50 taper current limit</td>
<td>60A to 2.8V</td>
</tr>
</tbody>
</table>

- All 4 are mature cell designs, made in high volume production lines
- All 4 provide a blend of high power and energy density capability
Test Plan for Assessment of Cell Designs

• **Acceptance Testing**
  – Visual, OCV, AC Impedance, mass, dimensional
  – Pouch isolation resistance
  – Soft short (OCV bounce back after deep discharge)

• **Capacity performance**
  – Capacity/Energy vs rate
    • at ambient T, C/5, C/2, C, 2C, 4C with 3 cells per design,
    • all charging at manufacturer recommended rate

• **Cycling performance**
  – Capacity/Energy vs cycle number
    • 4C discharge, C/2 charge at ambient T for >100 cycles

• **Evaluate cell design and manufacturing quality**
  – Seal leak rate and compare to 18650 crimp seal rates
    • Seal cells in Al laminate bag with dual element impulse heat sealer
    • Then thermally cycling (vs not) for 3 weeks
    • Sample gas trapped in outer bag
    • Measure trace concentrations of electrolyte components via GC/MS to calculate leak rate in volume/time
      – Compare leak rates per Wh, seal perimeter
  – Corrosion susceptibility
  – Destructive Physical Analysis (Tear down)
EIG Cell Discharging at 80A

Cell Voltage, Current vs Time
EIG 20Ah Cell Design p/n C020
s/n 2385, 2386, 2387
4C (80A) discharge at RT

Voltage 2385
Current 2385
Voltage 2386
Current 2386
Voltage 2387
Current 2387
Comparisons of Demonstrated Performance

4C specific energy and energy density comparison

<table>
<thead>
<tr>
<th>Vendor</th>
<th>PN</th>
<th>4C rate Energy</th>
<th>Average mass</th>
<th>Specific Energy</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Volume</th>
<th>Energy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>A123</td>
<td>PHEV</td>
<td>55.01 Wh</td>
<td>509.6 g</td>
<td>107.9 Wh/kg</td>
<td>227 mm</td>
<td>161 mm</td>
<td>7.2 mm</td>
<td>0.26314 Wh/L</td>
<td></td>
</tr>
<tr>
<td>DK</td>
<td>SLPB75106100</td>
<td>26.34 Wh</td>
<td>165.0 g</td>
<td>159.6 Wh/kg</td>
<td>102 mm</td>
<td>106 mm</td>
<td>7.8 mm</td>
<td>0.08433 Wh/L</td>
<td></td>
</tr>
<tr>
<td>EIG</td>
<td>C020</td>
<td>64.48 Wh</td>
<td>429.4 g</td>
<td>150.2 Wh/kg</td>
<td>216 mm</td>
<td>130 mm</td>
<td>7.2 mm</td>
<td>0.20218 Wh/L</td>
<td></td>
</tr>
<tr>
<td>LG</td>
<td>P1</td>
<td>51.62 Wh</td>
<td>382.5 g</td>
<td>135.0 Wh/kg</td>
<td>226 mm</td>
<td>165 mm</td>
<td>5.5 mm</td>
<td>0.2051 Wh/L</td>
<td></td>
</tr>
</tbody>
</table>

- DK has highest specific energy (~160 Wh/kg) at the 4C-rate
  - However, also has highest temperature rise (28 C)
- EIG has highest energy density (~319 Wh/L) at the 4C-rate
  - 2\textsuperscript{nd} highest specific energy (~150 Wh/kg)
Variations in as Received OCVs

Vendor

A

B

C

D

Sdev%
Range%
3s Range%
4 cells out of 20 had declining OCV between days 10 and 14
OCV recovery vs days after deep CV discharge at minimum operating voltage to a taper current limit of C/50, while at 23 degC. Cells with declining OCVs have soft (high impedance) short.
OCV recovery vs days after deep CV discharge at minimum operating voltage to a taper current limit of C/50, while at 23 degC. Cells with declining OCVs have soft (high impedance) short.
DPA Results of Failing Cells

• Cells failing the OCV bounce back test were from lots made on consecutive days
  – Cells made on other dates passed all acceptance tests
• OCV bounce back test after deep discharge (soft short test) was effective at non-destructively identifying cells with defects (in case of worst performing cell, defect was confirmed by DPA)
  – 2 large halos detected on one anode,
    • one with a crystalline piece of FOD consisting of Fe, Mg, Si, Al
    • And with a small piece of Al NOD
Crystalline FOD consists of Fe, Mg, Al, and Si
SEM/EDS of NOD

- Piece of Al debris on anode
- Found near the bigger FOD
Pouch Corrosion

• Procedure
  – Polarize Al layer of pouch to the negative potential of the cell
  – All four cell designs tested for up to 2 months

• Results
  – Within 2 weeks, the pouch corrosion sites on Vendor D cell developed several wide, black blisters
  – The cell pouch no longer appeared tightly fitted around the cell electrode stack
Pouch Corrosion (cont)

- Vendor C Results
  - Within 4 weeks, the pouch corrosion sites on cell developed, one black and one small, gray blister, both on the corners
  - The cell pouch no longer appeared tightly fitted around the cell electrode stack
- Results on the other 2 designs
  - No evidence of pouch corrosion after 2 months
- What cell design attributes do pouch corrosion resistant cells have that the others don’t?
Other Examples of Pouch Corrosion

- Defective inner isolation layer of the laminate pouch results in corrosion of the Al layer
- Polarizing the Al layer to the (-) terminal is a quick test method

Photo courtesy of NREL
Conclusions To Date

• Current Li-ion pouch cells designs for electric vehicle market are offering
  – Over 150 Wh/kg and 300 Wh/L at 15 minute (4C) discharge rates
    • Verified by test with 2 cell designs
• Soft short test (or OCV bounce back test) is an excellent discriminator of manufacturing quality
  – Preventing battery assembly with cells with charge retention issues
  – Help precluding battery assembly with cells with latent defects
• DPA’s are also an excellent way to assess manufacturing quality
• Two cell designs were resistance to our pouch corrosion test
• Planned testing will determine their readiness for the demands of crewed spacecraft
  – Manufacturing quality
  – Effectiveness of the seals
  – Durability of performance